SPECIFICATION
(MBHB Case No. 02-1251)
(CMC Case No. 100116)

Title: Micromachining by Chemical Mechanical Polishing

First Inventor: David G. Mikolas
Citizenship: United States of America
Address: 17800 Colima Rd., Apt. 386
Rowland Heights, CA 91748

Second Inventor: Ian W. Wylie
Citizenship: Canada
Address: 1312 Hamlet Rd.
Naperville, IL 60564

Assignee: Cabot Microelectronics Corp.

Application Type: U.S. Patent Application

MICROMACHINING BY CHEMICAL MECHANICAL POLISHING

BACKGROUND OF THE INVENTION

Field of the Invention

The invention relates to micromachining techniques. More particularly, the invention relates to methods for micromachining substrates into defined structures using chemical mechanical polishing.

Description of the Related Art

Chemical mechanical polishing (CMP) is used in the integrated circuit industry for planarizing substrates. In a typical CMP process, the substrate is placed in direct contact with a rotating polishing pad. A carrier applies pressure against the backside of the substrate. During the polishing process, the pad and table are rotated while a downward force is maintained against the substrate back. An abrasive and chemically reactive solution, commonly referred to as a "slurry," is applied to the pad during polishing. The slurry initiates the polishing process by chemically reacting with the film being polished. The polishing process is facilitated by the rotational movement of the pad relative to the substrate as slurry is provided to the substrate/pad interface. Polishing is continued in this manner until the desired film is removed.

A substantial amount of effort is directed in the industry at maximizing the planarity of substrates being polished by CMP, and minimizing the formation of non-planar features, such as corner rounding, and dishing. As a result, CMP has not been considered by the industry as a micromachining tool.

Current micromachining methods have undesirable attributes. For instance, binary optics prepared by current methods typically radiate substantial power in

undesired orders, and have polarization dependent phase shifts. Consequently, new and improved micromachining methods are needed for optics fabrication and fabrication of other structures, such as mechanical devices, imagers, and displays.

SUMMARY OF THE INVENTION

The invention relates to micromachining methods using CMP. Thus, in a first aspect the invention provides a method for forming a substrate into a defined structure, said method comprising selectively removing at least a portion of the substrate by chemical mechanical polishing to provide the defined structure, wherein the defined structure is at least partially non-planar.

The invention also provides structures and devices formed by the methods described herein.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 illustrates the formation of a beginning structure using a deformed polishing pad.

Fig. 2 illustrates a polishing sequence that includes an initial step of high pad acceleration followed by subsequent steps of constant acceleration.

Fig. 3 illustrates the polishing of a feature under conditions of varying downforce.

Fig. 4 illustrates polishing of a feature by a pad having local curvature.

Fig. 5 illustrates polishing of a feature by a pad having asperities on its surface.

Fig. 6 illustrates the use of a buffer material in a polishing process.

DESCRIPTION OF THE CURRENT EMBODIMENT

This invention relates to a process for micromachining substrates into defined structures, using chemical mechanical polishing (CMP). Specifically, CMP is used to form structures that are at least partially non-planar. Examples of such partially non-planar structures include, but are not limited to, rounded structures, convex and concave shapes, and combinations thereof, as well as more complex structures. Such non-planar structures are generally functional and find use in many applications, including photonics, such as microlens arrays and optical fiber array connectors, mechanical devices, imagers, displays, and so on. In preferred aspects, the height differential between the highest point and the lowest point on the surface of non-planar structures manufactured according to this invention are 0.5 microns or greater. In other preferred aspects, the height differential is 1 micron or greater. In further preferred aspects, the height differential is 2 microns or greater.

CMP is a polishing process that exploits both chemical and mechanical polishing techniques for the polishing of a surface. Generally, the substrate is placed in direct contact with a polishing pad, and the pad, substrate, or both, are rotated while a downward force is maintained against the substrate back. A slurry, representing the chemical aspect of CMP, is applied to the pad during polishing. Alternatively, an abrasive containing polishing pad may, be used in which case the chemical ingredients of the polishing composition are applied to the pad during polishing.

In the invention, the characteristics of the polishing pad are varied such that the CMP polish, including the optional use of a chemical slurry, provides structures that are at least partially non-planar. The polishing pad characteristics that can be varied include

the stiffness of the pad. Pad stiffness can be manipulated by several properties of the CMP apparatus, including downforce on the polishing pad; rotational velocity of the polishing pad; and acceleration velocity of the polishing pad. In addition, stiffness is also a function of the pad material. Other pad characteristics that are advantageously utilized in the invention to form partially non-planar structures include areas of local curvature on the pad, areas of local increased or decreased downforce on the pad, and the presence of asperities on the pad. In addition, the position of the polishing pad relative to the substrate being polished, can be exploited to provide structures that are partially non-planar.

A substrate to be micromachined according to the invention preferably includes one or more beginning features upon which the polishing pad acts to effect a change in shape. Such a beginning feature can readily be prepared by semiconductor techniques known in the art. The choice of beginning feature will depend in part on the final geometry that is desired. One example of a useful beginning feature is a stepped structure. Alternatively, or in addition, the substrate may include two or more materials in the same plane that hve different properties, such as different polishing rates, to allow CMP to effect a change in shape.

The characteristics of stiffness of the polishing pad can be manipulated to provide rounding, such as corner rounding, of a feature. To achieve large amounts of corner rounding, it is desirable to have a pad that is not too stiff because it will deform more at the edges of a feature. The centrifugal force experienced by the pad at any point on its surface will determine the increase in stiffness of the pad (centrifugal force is controllable by the velocity and/or acceleration of the pad). Since the centrifugal force on any point

on a disk is proportional to the rotational velocity times the distance from its axis of rotation, the stiffness will increase as the distance from the axis increases. The increase in stiffness is approximately proportional to the square root of the increase in centrifugal force.

If a deformable pad, such as one made of a polymer with a significant elastic modulus, and which is not pinned at the back so it is free to deform, rotates at a small angular velocity it will tend not to be stiffened. In such a case, the degree of corner rounding will be great (see Fig. 1, illustrating a beginning structure 10 being polished by a deformed polishing pad 20). If the same pad is rotated at a significant rotational velocity, causing stiffening, the amount of corner rounding will be less. An adjustment of the relative distance of the feature being polished from the rotational axis of the pad can achieve the same result as adjusting the rotational speed of the pad because of the effect noted above. Fig. 2 illustrates a beginning structure 10 that is formed, for example, by a polishing sequence that includes an initial step of high pad acceleration followed by subsequent steps of constant acceleration.

The deformity of the pad can also be affected by the downforce on the pad. If the relative downforce being applied to the pad is greater it will tend to bend the pad to a greater degree than if the force being applied is of a lesser amount. A stiffer pad will deform less for a given applied downforce. Fig. 3 illustrates the polishing of a feature 10 under conditions of varying downforce. "F=0, F=1" vs. "F=0, F=0.01" refer to the relative values of "Force" being applied by the relative stiffness in the pad and the downforce applied during polishing. As discussed above, the more the pad is deformed, the greater the extent of corner rounding.

A further pad characteristic that can be exploited to produce controlled topography in the polishing surface, is localized non-planarities, bumps, grooves or other surface features on the pad itself. In a typical polishing operation, the polishing surface is moved over the surface of the pad in a circular motion. Therefore, any surface feature in the pad will affect the material in a circular fashion. A circular ridge or groove on the pad surface will tend to produce a linear feature on the polishing surface. A large ridge or large groove on the pad will tend to produce a corresponding large ridge or groove on the polishing surface. Using intermittent ridges or grooves disposed in a circular manner on pad surface will tend to reduce the rate at which the material was being removed but will tend to produce the same feature shape.

One advantage of pad surface features is the flexibility that it provides to produce a high degree of local curvature in the polishing surface. The deliberate juxtaposition of an existing surface feature on the pad and on the polishing surface can be utilized to produce a high degree of local curvature and counter-curvature (concave and convex curves on the surface in proximity). A cross-section of a surface feature being polished to produce both of these curves is shown in figure 4.

When material is removed from a step-shaped feature with a pad it is preferentially removed from the raised corners producing a bevel or convex shape. As long as the material has a finite removal rate outside the step shape, which can be increased through the use of a very compliant pad, there will be a tendency to produce a counter-curve or concave shape right beside the convex shape. After the removal of a significant fraction of the material forming the initial step (probably more than 50%), the

total length of the concave-curved surface will begin to approach the length of the convex-curved surface.

It is possible to produce this curve and counter-curve without a surface feature being present on the pad. However, it is easier to produce curves with a higher degree of curvature with the two sets of features on the opposing surfaces being in close proximity. The surface features in the pad which help to produce the surface features on the polishing surface should be of the appropriate size to produce the desired feature dimension.

Additional layers of material, such as buffer layers, may be used to underfill or overfill spaces between features on a substrate, thus further enhancing the CMP process. Such layers are described in published patent application number US 2003/0136759, which is incorporated herein by reference in its entirety.

When used, a buffer layer can assist in the formation various shapes on a feature, including convex and concave shapes. Figure 6a provides one example of the use of a buffer material 50 for the formation of concave surface on structure 10. When used for the formation of a concave surface on structure 10, the buffer material 50 should be a material that is removed by polishing at a rate slower than the rate at which structure 10 material is removed during the same polishing procedure. The preferential removal of structure 10 in comparison to buffer material 50 causes the formation of a concave surface to structure 10 during the polishing step.

Alternatively, buffer material can be used for the formation of a concave surface on a structure. In this embodiment, the buffer material should be a material that is removed by polishing at a rate faster than the rate at which the underlying structure

material is removed during the same polishing procedure. The preferential removal of buffer material in comparison to structure material causes the formation of a convex surface to the structure during the polishing step. The use of the two types of buffer materials (those that are polished more quickly and those that are removed more slowly) on the surface at the same time can be utilized to produce very complex shapes in polished materials.

A further example of the advantageous use of buffer material for the formation of partially non planar structures is depicted in figure 6B. In this embodiment, the buffer material acts as a stop layer, protecting any underlying structures from polishing. Thus in this embodiment, the buffer material 50 should be a material that is removed by polishing at a rate slower than the rate at which structure 10 material is removed during the same polishing procedure.

In the above embodiments, any buffer material remaining on the substrate following polishing can be removed by well known techniques such as chemical etching.

As noted earlier, it is preferred that all polishing steps described herein be conducted in the presence of a chemical polishing composition or slurry. The choice of polishing composition or slurry is an important factor in the CMP step. Depending on the choice of ingredients such as oxidizing agents, film forming agents, acids, bases, surfactants, complexing agents, abrasives, and other useful additives, the polishing slurry can be tailored to provide effective polishing of the substrate layer(s) at desired polishing rates while minimizing surface imperfections, defects and corrosion and erosion. Furthermore, the polishing composition may be selected to provide controlled polishing selectivities to other thin-film materials used in substrate manufacturing.

Examples of CMP polishing compositions and slurries are disclosed, in U.S. Pat. Nos. 6,068,787, 6,063,306, 6,033,596, 6,039,891, 6,015,506, 5,954,997, 5,993,686, 5,783,489, 5,244,523, 5,209,816, 5,340,370, 4,789,648, 5,391,258, 5,476,606, 5,527,423, 5,354,490, 5,157,876, 5,137,544, 4,956,313, the specifications of each of which are incorporated herein by reference.

While the present invention has been described by means of specific embodiments, it will be understood that modifications may be made without departing from the spirit of the invention. The scope of the invention is not to be considered as limited by the description of the invention set forth in the specification and examples, but rather as defined by the following claims.